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# The application of solar technologies for sustainable development of agricultural sector

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ABSTRACT

Solar energy is one of the cleanest sources of alternative energy. Due to high energy demand in one hand and environmental negative impact of fossil fuels, on the other hand, many countries consider the alternative energy sources as a suitable and feasible option in industry and domestic usage. It was discovered that the different applications of solar energy in industries are being accepted more than ever. The present study is a state of art on the numerous new and feasible technologies of solar energy applications in the agricultural sectors. It discusses about the importance of solar energy as environmental clean technologies and the most reliable energy source. This study covers different types of solar energy systems like as solar photovoltaic and solar thermal for pumping water, drying crops, cooling the storages and producing heating/cooling greenhouses. It has been proven that photovoltaic systems and/or solar thermal system would be the suitable options in agricultural application and especially for the distant rural area.

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**Contents**



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## 1. Introduction

“The sun radiates more energy in one second than people have used since beginning of time” [1]. The deep existent meaning of energy is the ability of sustaining and enhancing the life quality [2]. Energy has various forms like light, electricity, heat and radiation. For thousands of years, human used only renewable energy sources such as hydro, solar or wind, and agriculture in particular has been an action of employing the energy of solar to manufacture foods and besides that the human power was the only energy man used for it. Primary agriculture was first born from this model, which was soon changed when machineries came to the agricultural sectors to intensify outputs, which happened in all developing industrial countries. In fact, agriculture can be considered as one of the most critical industries that provides first necessities of living for human being who the same as other industries all activities and machineries in this area such as tractors, trolleys, cultivators, etc. also operate with conventional fuels such as petrol, diesel and fuel oil [3]. Moreover, industrial sectors have a major impact on the total energy consumption of all developed and under-developed countries [4]. Facing to the mechanized agriculture due to the many parameters such as land and labor cost and the energy sources is fairly different in different parts of the world [3,5]. For the time being, fossil fuels seemed to be adequate to support all human’s energy consumption needs, but now a day not only it is not sufficient forever, but has diverse impacts on the environment either. One of the most critical concerns in the world during the past few years was energy matters especially since by increasing the population and industries, the demands of energy increased rapidly. Additionally environmental pollution as well as global warming or climate change that caused by the resources of conventional energy can be counted as the other significant issue in the world which all are the other main reasons to find a suitable alternative energy source [6,7]. As an example it can be addressed to the disaster occurred in 2003, which caused more than $10 billion losses in agricultural sector and death of 20 thousand people [8].

While, during the last few decades, the solar powered systems have been developed intensively and more often are considered as a feasible energy source in industry. Primarily, this is due to reduce fossil fuels consumption consequently $CO_2$ emissions for environmental consideration by using the zero emission-technologies and respond quicker to the demands of energy, especially in remote areas with available and more reliable energy source. While solar energy were first introduced for applying in electrification and telecommunication parts in rural sectors, moreover, there are huge requests of solar technology in other industries such as solar water heating, solar drying and solar PV [9,10]. The major objectives of this research are to: (1) classified all information about the present status of solar technology for supplying in different parts of agriculture sectors especially for remote areas and (2) introduce the different types of solar systems and discuss about their performances and advantages in altered applications.

In the context of this study, the different applied solar technologies in the agricultural sector are reviewed and classified. The solar irrigation systems will be reviewed first in Section 2 and then the solar refrigerator and cooling storage systems will be described in Section 3. The solar drying technologies will be evaluated in Section 4 and finally; the solar greenhouses will be presented in Section 5.

## 2. Solar irrigation systems

Comparing with conventional fuel, solar water pumping system has numerous advantages, for instance, besides of no cost for fuel and maintenance, the system it has no noise and pollution for the environment. Although there are solar water pumps with high capacity (10 of kW can be used), usually the pumps that are used in remote areas are small scale one (usually less than 1500 W) [11]. The main issue regarding to these systems is maintenance while at the same time 24 h electrical service is not demanded [12]. Solar water pump system is generally divided into two groups; solar photovoltaic and solar thermal water pumping systems.

General considerations of solar water pumping systems are described in Section 2.1. The different types of solar photovoltaic systems are explained in Section 2.1.1 and the effective parameters of the performance of the solar photovoltaic water pumping system are analyzed in Section 2.1.2.

### 2.1. Solar photovoltaic water pumping system (AC and DC motors)

Solar photovoltaic water pump consists of five parts, which are explained through the Table 1.

Solar photovoltaic water pumping usually does not include any battery backup, which appoints the system lower cost, standalone PV system and maintenance free, which make the photovoltaic system suitable for different pastures. The system is also equipped with automatic turn off mechanism, which shut down the pump when the tank is full. The system of photovoltaic that converts sunlight into electricity is based on the technology of

**Table 1**
Components of solar water pump system and their description.

| Component | Application | Types | Description |
|---|---|---|---|
| PV array | Source of electrical energy | Amorphous, mono-crystalline poly-crystalline.(mono-crystalline has the highest efficiency while amorphous has the lowest). | PV array is analyzed based on the *I–V* curve and each array has its own disposition. Consequently many factors such as temperature, the load and radiation can affect the maximum power point or MPP. |
| The pump | Draws water from reservoirs, deep/shallow wells | Floating pump, submersible, surface pumps. | The selection of pump depends on; water requirement, the height of water (well), and the quality of water. |
| The motor | Pump and draw water from well | AC/DC, brushed/brushless, permanent magnet, synchronous/asynchronous, variable reluctance, | If the system works with DC, the PV array could be directly connected to the motor, otherwise an inverter/controller located between the motor and PV array. |
| The controller | Mandatory part if the motor is AC | N/A | Although it is one of the defenseless part of the system, but it can provides the optimum voltage/current by isolating different parts while also protects the motor from running dry and conserves water by turning off the system when the tank is full. |
| Water storage tank | Saving spare water | N/A | |

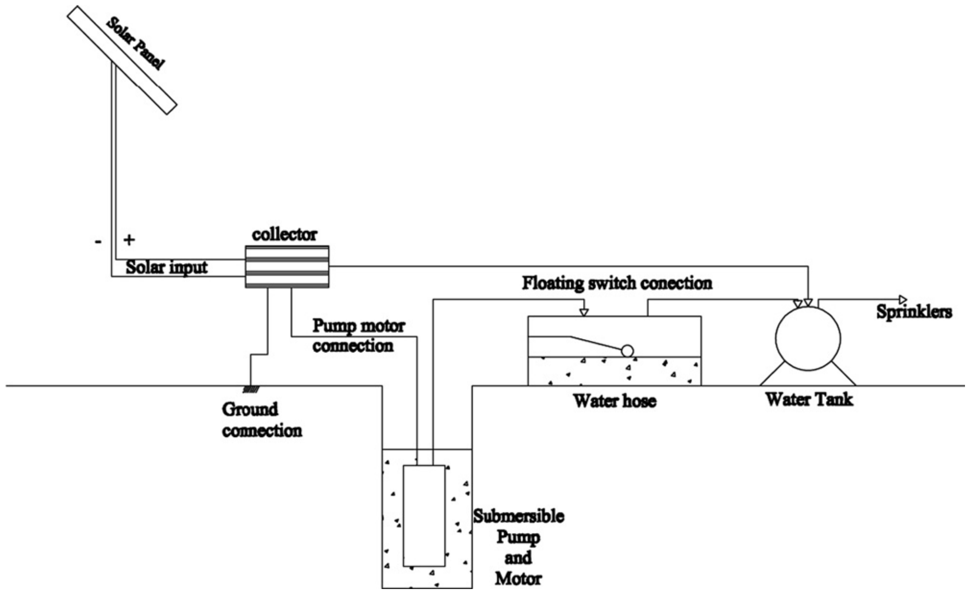


**Fig. 1.** Schematic diagram of photovoltaic water pumping system [12].

semiconductor and although this technology is established now, but its costs are still more than other electricity generation methods. Fig. 1 is the overall schematic diagram of the photovoltaic water pumping system.

In order to check the feasibility of applying the solar system, two general way are considered: economic and environmental aspect.

### 2.1.1. Economic aspect

The total capital needed for installing the system of photovoltaic comprises all part of the system such as the panels, inverter or controller, cables of power, pump and pipe. Considering from this point that the system of photovoltaic does not have the operation cost compared to the diesel generator who has very high cost of maintenance while its efficiency drops with time, it can be proved that even with higher capital cost of PV panels than diesel generator, photovoltaic water pumping system is the most cost effective for remote areas. Overall look on the economic comparison between solar photovoltaic system, electric gird and diesel fuel shows that the highest capital cost is for electric utility the same as operation and maintenance cost, which is higher than PV panels. On the other hand, after 10 years the replacement for both PV panels and electric utility is only the controller and/or pump while for the diesel generator, the only replacement is to buy new both generator and pump. Meah et al. [12] by calculating the total cost of the life cycle within 25 years with the same assumptions for all three systems which were diesel generator, electric grid connection and solar energy, proved that the photovoltaic system is the most suitable option for remote rural areas while it has the lowest cost of the life cycle.

### 2.1.2. Environmental aspect

The next parameter for choosing the suitable water pumping system is determining the impact of each system in the environment. Besides the serious environmental pollution caused by carbon dioxide emission, mostly by using fossil fuel, carbon dioxide emission is a strong indicator of economic growth of each country. By simple calculation of the carbon dioxide emissions from different fossil fuels for a water pumping system, PV panel life cycle proves that only system does not have any adverse effect on the environment is the photovoltaic system while the diesel generator has both air pollution and sound pollution and electric utility system generated by windmills, although does not produce any air pollution, but it makes sound pollution and also has a considerable visual impact.

The conclusion of all these calculations and comparison is the suitable installation and design of a system in order to supply sufficient water for the agricultural purpose.

### 2.1.3. Types of solar photovoltaic pumping systems

An overall explanation about how the photovoltaic water pumping system works was reviewed. As it was mentioned before the system has two general models: AC and DC. Since the PV system has been invented most of the researches had focused on the DC motors or direct-couple photovoltaic and their functions. Firatoglu and Yesilata [13] found out that at insolation range of the DC motors with the direct-coupled system, the maximum power point (MPP) of the photovoltaic arrays significantly diverges from the operating points while Short and Oldach [14] and Short and Burton [15] proved that in the continuous different weather condition, a direct-coupled system operates at MPP of the photovoltaic array.

Benlarbi et al. [16] demonstrated that contrarily with DC motors, since in AC models the system works by inverters and induction motors. Therefore, it can be a better option and with having stronger induction motors AC motors are free of maintenance and with lower cost the system it has more diversity and availability, which totally make the system more reliable while DC motors have serious problems with system maintenance [17]. Odeh et al. [18] also came up with the effect of the pump and well mismatching on the performance of AC motors, determining the sufficiency of the system under different conditions and finally calculating the best possible size of the PV array based on the analyzing the cost of the system's life cycle. In general, AC motors can offer more occasions for control strategies and improving the efficiencies.

On the other hand, the photovoltaic water pumping systems have some issue. Jafar [19] counts some factors that make replacing the solar water pump with conventional pump not practical. Some of these issues are: system high initial cost, insufficient information about solar systems, lack of technician and expertise for installing and maintaining and lack of knowledge to forecast the daily output

of the system. Short and Oldach [14] considered that the design of the pump can cause the problems too, i.e. for the maximum results of PV water pumping the correct size of each parameter is needed.

### 2.1.4. Techno-economic aspect

According to the high price of the PV panels in irrigations and by considering the characteristic of the soil-type, crop and the elevation of pumping, Cuadros et al. [20] came up with photo-irrigation theory for the first time which is the arrangement with three main levels: (1) settling the requirements of irrigation based on the climatic condition and soil type characteristic, (2) due to the depth of the aquifer sources pumping estimating the hydraulic analysis and (3) ultimately calculating the peak photovoltaic power required for irrigation. With refer to their analysis, it was shown that photo-irrigation system has the potential of being the immense strategies in irrigation and improves crop production, efficiency of using the source of solar energy and water in order to make a suitable occasion for rural sustainable development.

While analyzing the technical direction of the solar photovoltaic water pump system is essential, nevertheless, the economic feasibility of the solar energy is also fundamental, which enthused Kelley et al. [21] to work on the feasibility of solar-powered irrigation that declared as a function of climatic condition, cost and depth of aquifer as well as local political policies and as a result compared the solar water pump with the diesel and electrical grid powered system in cost (capital, operating and maintenance cost) and environmental impact that all their findings and result summarized in Table 2.

Kelley et al. [21] investigated some factors affect the feasibility of the system such as type of crop, geographic location, climatic condition, depth and the rate of recharging water, costs of conventional energy, government procedures and rule i.e. the taxes of carbon and as the same as other, studies proved that solar irrigation system is feasible when low power needed, which means that from shallow wells or low flow rate pumping from deep wells. Following the method of sizing the PV panel, they concluded the area of solar array necessary land either which is the only important parameters for the technical feasibility of the system. On the other hand, geographic location and the type of crop verify economic feasibility of the system.

### 2.1.5. Affective parameters on the solar water pumping efficiency

The influential parameters which affect design of the solar system significantly can be counted as solar radiation, the source of water, the amount of required water, and duration of using the system in a year, the same as getting the information about the necessary amount of water for an agricultural particular application, the characteristics of well or any other water sources, and the ability and facility of water storage which after supplying water conservation is next important parameter. Glasnovic and Margeta [22–25] analyzed the possible effects of other elements in the photovoltaic water pump system such as local climate, type of soil, irrigation area, depth of well, crops type and irrigation method, which is explained in Table 3 and proposed the mathematical model for sizing photovoltaic pumping system in order to claim for hydraulic energy from the accessible energy of solar and its possibilities.

## 2.2. Solar thermal water pumping system

Delgado-Torres [26] reviewed the thermal energy of water pumping system, and the different types of solar thermal energy based on the thermodynamic methods are shown in Fig. 2 schematically.

While simple solar thermal water pumping system usually has low effectiveness and low output power, there are two alternatives for the thermo-mechanical conversion; conventional that pump is moved by mechanical energy and unconventional in which the specially designed system of water pumping is driven by mechanical energy.

The second type of solar thermal energy is based on the unconventional thermodynamics which its system principle operation is almost the same as conventional thermodynamic. In general, the characteristic of the system can be considered as (1) the pumping of water caused by working fluid evaporating and heating, (2) water suction and lifted caused by the alternative

**Table 3**
Effects of different parameters in the system performance.

| Elements | Effects on the power of the system |
|---|---|
| Climatic condition | Different changes in climatic conditions such as changes in humidity or the sun radiation have influences on the optimal nominal power since first factor affects the water requirement and the second one makes the efficiency of the water pump system changed. |
| Depth of well | Declining water static level in well causes increasing the photovoltaic pumping optimal nominal power. |
| Irrigation area/type of crops | By increasing the area of irrigation which means rising the requirements of watering the crops or variety types of crops who call for more water, the optimal nominal power of PV pump system increased either. |
| Type of soil | Lower capacity of soil makes nominal power increase while increasing the depth of soil, decrease the nominal power and by increasing the moisture of soil, the power of PV generator decreased. |

**Table 2**
Comparing different energy sources technically and economically.

| Source of energy | Economical feasibility | Technical feasibility |
|---|---|---|
| Solar water pump | The capital cost is higher than diesel and electrical grid while the maintenance and operating cost is negligible. Moreover the price of solar panels decrease every day which make the system more beneficially. | No technical barrier for solar installation except (1) the availability of the land and solar insolation which is the radiation received over the course of a day at the surface of earth and is measured in kWh/$m^2$/day and is a critical factor and (2) the area of solar array. |
| Diesel generator | The price of the fossil fuels increased significantly each year which affect the economic feasibility of the system who works with diesel generator. In addition, since diesel generator consist of air, oil, fuel, water separator filters with lubricant oil change and engine coolant change which all affect the operating and maintenance cost of the system and total cost will be the sum of all of them. | As this system consist of many factors, diesel generator is feasible technically when all the parameters are feasible. |
| Electrical grid connection | The maintenance and operating cost of the system is negligible. | Same as the diesel generator. |

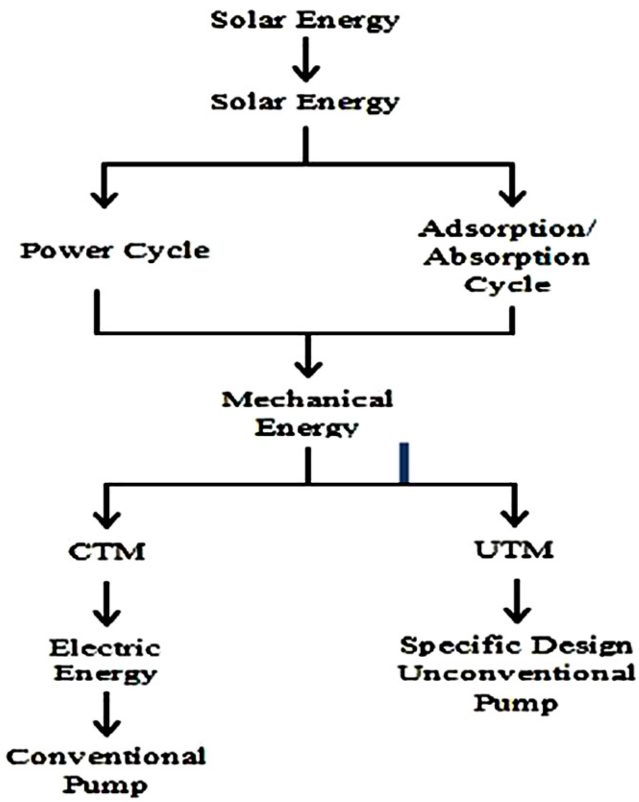


**Fig. 2.** Flow chart of solar thermal water pump system [26].

**Table 4**
Summary of reviewed papers for solar irrigation systems.

| No. | Solar pump technology | Key result | Ref. |
|---|---|---|---|
| 1 | Solar photovoltaic water pump | The system has two types AC/DC and no need to backup battery which makes it more cost effective and maintenance free but only applicable for small-scale area. | [12–21] |
| 2 | Solar thermal water pump | The system has two types, UTM and CTM. By comparing with PV system, solar thermal water pump is low effective with lower output. | [26] |

gas heating and cooling and (3) the generated gas adsorption pressure reduction which applied for the pumping water from a lower level caused by chemical heating compound.

The process of solar water pumping can be performed with two different methods, the method of direct convention in which the converted solar energy to the electricity runs the DC/AC motor while the other method is thermodynamic that convert the thermal energy of sun into mechanical work (Table 4).

## 3. Solar cooling refrigerator and storage

One of the most imperative factors to guarantee the quality of agricultural storages is the internal temperature of the store. In fact, with low temperatures infestation of insect, growing mold can be prevented while it helps to reduce the grain respiration, which influence on the time of extended storage. Consisting of a great number of researches showed that the mechanical vapor compression refrigerating system with high capacity chillers can control the temperature of storage during hot summer seasons [27–32], while, on the other hand, these systems are not economically feasible due to the high consumption of electric power and costs of operation. Since the availability of solar energy has the direct effect on the load of cooling inside the storage, the refrigerators with solar-powered adsorption systems appear to be a practical choice. Luo et al. [33] calculated the suitable temperature for grain storehouses during cold seasons that the grains are cooled to below 5 °C by mechanical ventilation and hot seasons when the temperatures of middle and bottom grain layer are kept below 15–20 °C while in some hot areas, the temperature of upper layer arrived at 32 °C. Therefore, one of the grain storage major concern is maintaining the temperature between 15 and 20 °C continually. One solution can be using the refrigerators with mechanical vapor compression to keep the temperature below 14 °C.

Besides the suitable temperature, moisture of the storage is the other important parameter [34–40] as dry and cold air ventilation may have an adverse effect on the grain quality, thus in order to avoid moisture condensation in the storage, the ambient air should be first dehumidified and cooled then exactly before joining the bin it should be reheated to get to the suitable temperature which asks higher energy consumption while the COP of the system is low. A key to this difficulty could be headspace cooling by fan coil unit then circulated into a mixture of ventilation pipes and by controlling the difference between the temperature of the fan coil unit inlet and outlet, the system easily passes up the moisture condensation.

### 3.1. Photovoltaic refrigeration system

Photovoltaic system which made from semiconductors includes two models: polycrystalline and mono-crystalline. In PV cooling system, batteries or generators always are used as a backup power [41–46]. The main characteristics of PV refrigerators are simple construction with high efficiencies [47] although to make the system practical for commercial purposes, still there are several challenges. First of all, the systems should be equipped with some means to cope with altering the rate of producing electricity with time, such as electric battery, mixed use of solar-grid-electricity or a compressor with variable-capacity. Second of all, the price of a solar photovoltaic panel should be much less than the other cooling technologies.

### 3.2. Solar thermal refrigerators

Solar thermal systems generally consist of two main categories, sorption refrigerators [48], and thermo-mechanic [47]. The first three systems are more practical and cost effective than the thermo-mechanic model which as the same as photovoltaic or any solar electric system is not economically feasible for solar cooling technology. In fact, in systems with solar thermal the heat is used more than the electricity of solar energy. The most common type of solar thermal systems is the collector of flat-plate and evacuated tube.

Solar collectors supply the heat to the thermal compressor thus the working temperature of the system determines the effectiveness of the collectors. In the other word in higher temperature normally the heat engines work more efficiently while the solar collectors release more heat to ambient air and deliver less heat. These two disparate modes design and make the structure of a solar thermal system.

#### 3.2.1. Thermo-mechanical refrigerator

Thermo-mechanical engine means a system that converts solar thermal to mechanical work. In the cooling system, this function, consequently, drives a mechanical vapor compressor of

**Table 5**
Summary of reviewed papers for solar cooling systems.

| No. | Cooling technology | Key result | Ref. |
|---|---|---|---|
| 1 | PV system | The system has two types, simple construction and high efficiencies. | [41,47] |
| 2 | Solar thermal | The system has four categories and is cost effective specially in high temperature. | [47,61] |
| 3 | Thermo-mechanical | The system is more efficient with higher temperature and large-scale solar system. | [47,49,50] |
| 4 | Sorption | The system divided into two types and able to work with the low temperature energy while has no need to any special msaintenance. | [47–52] |
| 5 | Desiccant | The system is suitable option for industry with more compensation since it works with the lowering peak electric. | [46,56] |

a refrigerator [49,50]. Higher efficiency of the refrigerators with thermo-mechanical technology is achieved when (1) the system works with the higher temperature of heat source and/or (2) when the large-scale of solar system would be available.

To make the solar thermo-mechanical refrigerators more competitive in the market, the price of a system contains of the heat engine, and solar collector should be comparable to a photovoltaic system. By comparing the price of both systems it can be found that a solar thermo-mechanical refrigerator is more expensive than a photovoltaic refrigerator. Thus economically, this system is not feasible [47].

### 3.2.2. Sorption refrigerators

Although the refrigerator by sorption technology was a niche technology at first but after a while and due to many advantages such as environmental friendly, being noiseless, reliability of the system and low maintenance cost, it became more popular and the demand for that system increased especially with the new models which is able to work with the temperature lower than 100 °C that make the system using low temperature energy.

*3.2.2.1. Absorption.* One of the most common systems in solar cooling is the refrigerator with absorption technology as it needs very low or sometimes no electric input. Comparing absorption and adsorption systems shows that the absorption machines are usually smaller than adsorption machines for the same capacity, and it is because of transferring the absorbent high heat coefficient. In addition, the quality of being fluid of the absorbent system makes the system be more flexible in actualizing a more efficient machine [51].

*3.2.2.2. Adsorption.* Adsorption refrigerators or in the other name, "Physisorptions" are divided into two main categories: intermittent and continuous and there are two types of adsorptions; physical adsorption and chemical adsorption. Physical adsorbents have the structure full of poriferous with the hundreds ratios of surface-volume that are able to catch and hold refrigerants selectively. They can easily be renewed by being heated after saturation [47]. In the adsorption process fluid molecules are stabilized on a solid material's walls [52]. As the adsorbent must be regenerated by the time it is saturated thus the process is not continued and because of that, for continuous operation variety beds of adsorbent are necessary.

*3.2.2.3. Desiccant cooling technology.* For a certain application of cooling, the technology of the desiccant cooling system has become a valuable tool in the industry. Comparing with the adsorption/absorption cooling system, desiccant technology has more compensation. As it works with the lowering peak electric, it can easily use solar thermal energy while it does not need the refrigerants that depleting the ozone layer. To get the better quality of indoor air both solid and liquid desiccant used in air-condition system. Recent researches [53–60] in the solar desiccant cooling system has focused on improving the desiccant materials that give better capacity for sorption, favorable equilibrium isotherms, and better moisture and heat rates.

With comparing different technologies in the cooling systems, desiccant dehumidification is more efficient in controlling the humidity than the other technologies and at the time of asking for a large ventilation or dehumidification; solar desiccant dehumidification system can be a suitable alternative (Table 5).

## 4. Drying the agricultural product

During the past three decades, various types of solar dryers have been discussed and analyzed. Most of the solar dryers systems have been designed for specific products and accordingly, the parameters such as quality requirements; characteristics of product and economic factors affect the solar dryer choosing for a particular product. In fact, there are four types of solar dryers; direct solar dryers, indirect solar dryers, mixed-mode dryers and hybrid solar dryers. Any solar drying system can be categorized in two general groups: natural and forced convection solar dryers. The first one also called as passive dryers while the second one called as active dryers. El-Sebai and Shalaby [62] and Fudholi et al. [63] organized and developed a systematic classification of all type of solar dryers which is showed in Fig. 3 based on system design and solar energy utilization mode.

Furthere more, Fadhel et al. [64] proposed a chemical heat pump dryer for agricultural products since they believed that the combination of solar technology and chemical heat pump make the system more efficient in energy utilization. Their generilized classification showed in Fig. 4.

In order to be in a safe side and guarantee the quality of the product [65,66], heat pump low temperature thermal makes the system an admirable match for domestic and industrial thermal applications and there are three influencing factors regards heat storage that affects drying the product:

(1) Based on the stored energy, drying period can be extended.
(2) To keep away from over drying the products, extra energy can be stored.
(3) To stay away from any material damages the drying air temperature can be controlled.

Moreover, the structure of all types of solar dryers consists of three parts: solar plan collector, drying box and chimney. Important parameters for designing a solar dryer are, collector design, efficiency of system, storage unit and drying system practical life. El-Sebai and Shalaby [62] Bennamoun and Belhamri [67], Forson et al. [68,69] and Aktas et al. [70] designed, calculated and modeld a natural convection solar dryers or in the other word passive dryer solar batch with solar collectors technical instructions, which showed in Figs. 5,6 and 7.

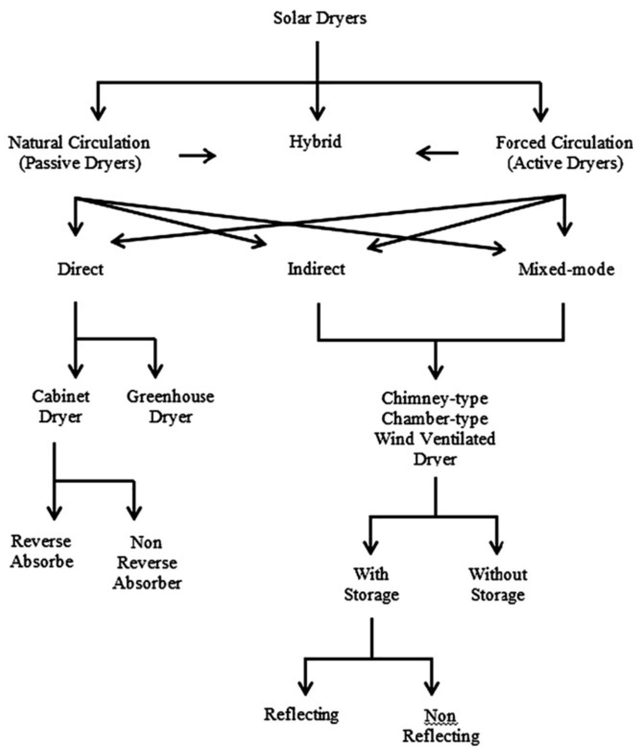


**Fig. 3.** Schematic diagram of solar dryer classification [63].

Drying chamber typically consists of the insulator consists of the plate made of Polystyrene, which at the same time can support easily 10 trays. The advantages of this solar batch dryer are, requiring low space, easy operating and maintenance.

The structure of air flat collector is not complicated. The system is composed of: the glass pyrex plate which has 0.01 m thickness, an aluminum plate absorber by 0.001 m thickness and finally, the polystyrene plate insulator by 0.04 m thickness [67]. While the dryer chief part is solar collector, and consequently, its length has the significant role in dryer with its output temperature direct effect, therefore, by the maximum surface convection thermal exchanges increases. Thus, the absorber design cannot be wavy, which means it cannot be arbitrary and has a specific shape for increasing the efficiency. The other important part in collector is a insulator glass wool layer as well as the inner part for reducing thermal loss while the absorber is covered by silvered surfaced radiance transmitted part. As a final point, stagnant air cavity between absorber and cover which the same as greenhouses roles, traps the transmitted radiance through the cover. This function stores and keeps the heat until stagnant air saturation level to provide the heat for the absorber.

In the type of dryer chamber, a fan circulates the heat which causes the best drying processes to control while inside the drying chamber it also makes distributed air homogenized. In unfavorable climatic condition and by the time that air outlet became lower than 50 °C an external heater will be the system supplementary.

To check the collectors, the other climatic information is required such as the temperature of ambient air, the speed of wind and solar radiation, collectors' temperature distribution and lastly air temperatures input and output. Furthermore, the temperature of air and characteristic of product are the other drying affective parameters. For more collectors' efficiency, the bench is stabilized and acted under two rules; the force and free flow. In both cases, the fan is employed for circulating the air; the first one works with variable speed while the second one has lower efficiency.

Based on different solar dryers analyses [63] and [71–74] the overall disadvantages of the solar dryer can be considered as: (1) system is not applicable for industry and commercial purposes since the capacity of the crops system is small (2) considerable time for drying process is essential, (3) due to the moisture evaporation and consequently, its condensation on the glass cover, transmitting glass cover is necessary, (4) due to over-heating the crops by direct exposure to sunlight the risk of deteriorating product quality is high and finally (5) the system may not work efficient enough since a part of the input solar energy is used to induce airflow while the product acts as the absorber.

### 4.1. Energy storage

After all explanation about the function and structure of the solar dryer system, another factor which becomes essential is energy storage. Storing energy can be an explanation of intermittent renewable energy sources, in order to synchronize demand and supply of energy. For energy storage in different forms such as electrical, mechanical and thermal energy, several technologies are available. Particularly thermal energy can be stored in well insulated fluids or solids as a change in material internal energy as latent, sensible and thermo-chemical heat or combination of all. Fig. 8 shows the storage major technique of solar thermal energy.

Numerous researches [71,75–78] discussed about the storing energy and proposed a phase change material theory as a latent way of storing the heat. In this method, to store and release heat chemical bonds are used. When the chemical bonds with the material break up, then transferring the thermal energy occurs since the phase change material from a solid becomes a liquid or vice versa. This is a "Phase" or a change in state. Originally, in this type of phase change temperature increases as it absorb heat which is the same as the function of conventional storage materials but against the conventional storage materials, when phase change materials get to the changing phase temperature which means their melting point they are able to absorb large amounts of heat without getting hotter, which make the temperature fix during the melting process. This heat called as a latent heat and has two major advantages: (1) large amounts of heat can be stored with only small changes in temperature, which caused high storage density and (2) due to the time the system needs for completing change of phase at a stable temperature, any changes in temperature is smooth. Therefore, by phase change material technology heat storage can be 5–14 times more than sensible storage materials such as water, masonry, or rock. A classification of phase change material showed in Fig. 9.

## 5. Solar greenhouses

Many papers are available in solar greenhouses [79–86], but not necessarily all of them are applicable in this area. Sethi and Sharma [87] and also Ghozal et al. [88] proposed a model called earth-to-air system (EAHES) which can be considered as the only accessible system that has gained the suitable temperature control of the greenhouses within the last few years. The system works by burying the pipes in the depth of 2–4 m to use the potential of the heating, and the main problem of the system is related to this digging as it costs a lot, burying the pipe is not easy and after installation, monitoring of the system is not feasible while the system is not that much efficient.

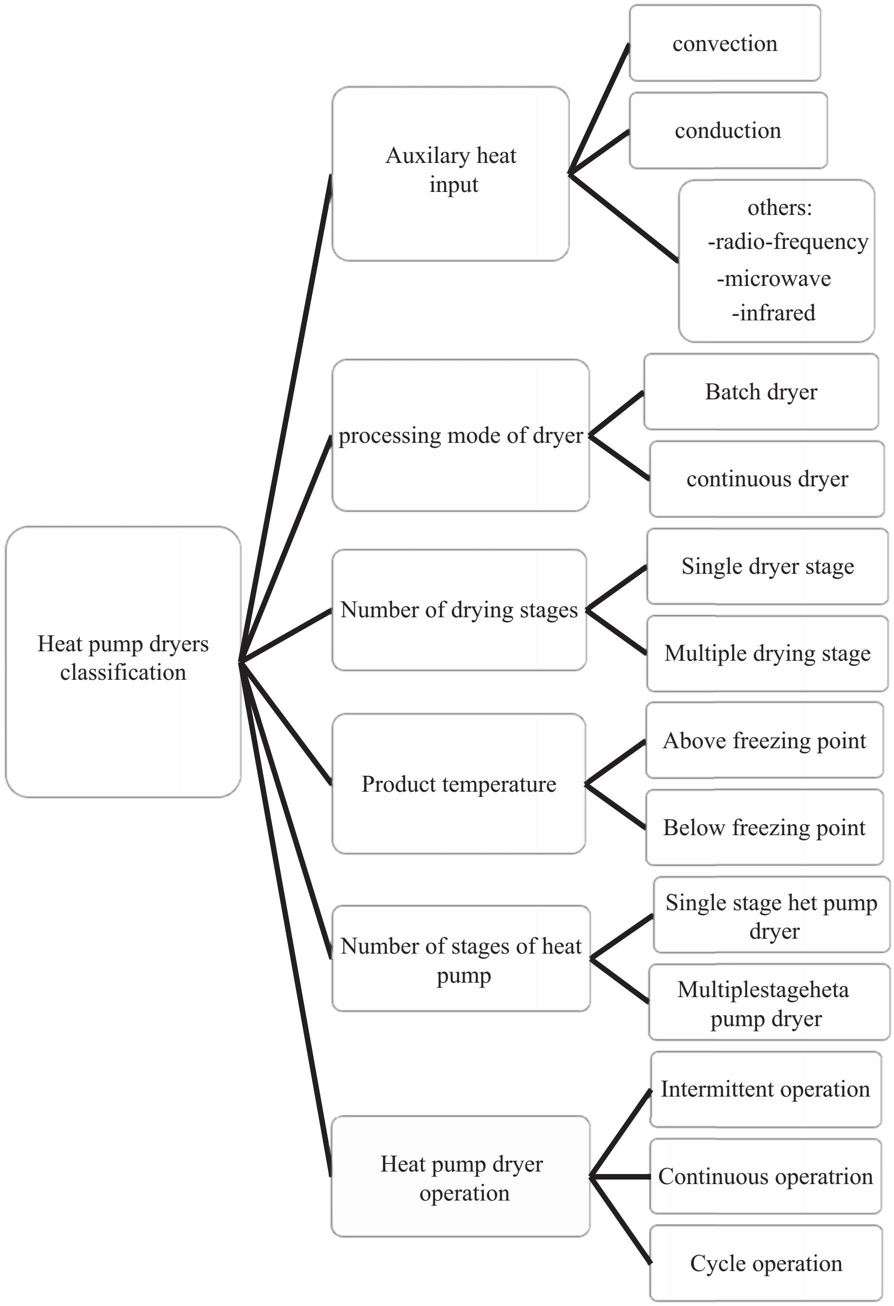


**Fig. 4.** A generalized classification scheme for heat pump dryers [64].

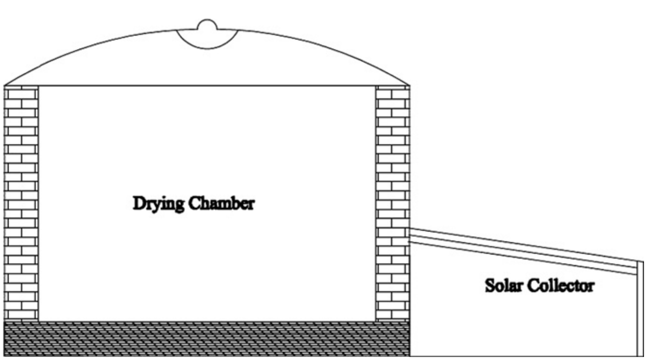


**Fig. 5.** Schematic diagram of typical solar batch dryer.

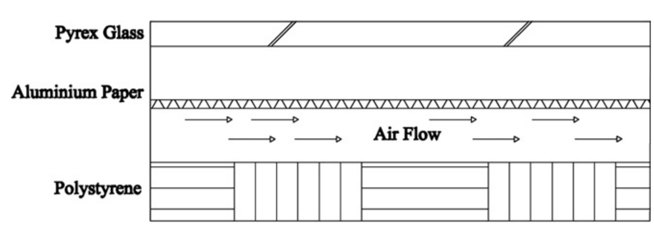


**Fig. 6.** Schematic diagram of solar collector.

ACCFHES is the other choice for cooling and heating the greenhouse during the days in summer and nights in winter is, which is an integrated thermal model with an aquifer coupled cavity flow heat exchanger system works through the utilizing

deep well, which would be accessible at the ground by a well tube of irrigation, which has installed in the field at fix 24 °C temperatures [87]. This model is more essential and efficient for both processes of cooling and heating in a greenhouse air. It can also help to improve the temperature of the plants inside the greenhouses, so it helps to have the maximum production.

ACCFHES has some advantages in comparing with EAHES:

1. Lower cost of installation due to the negligible digging cost of the system.
2. Availability of the aquifer water at the certain temperature due to the constant temperature of the ground (26–28 °C) which helps the system to keep the appropriate needed temperature (24 °C) for improving the cooling system.
3. According to the water and air arrangement of counter flow, the system give more heat to the air circulation, therefore, the system needs less power.

However, the mentioned system is one of the few feasible options for solar greenhouses, but it does not mean that it has no infirmity. It can be mentioned that the energy equations' fundamental balance in the specified climate condition for the different parameters such as solar radiation, the ambient air temperature, the wind velocity should be all considered. In addition, the physical factors such as shape, height, place and orientation have the significant part in primary design and cannot be negligible.

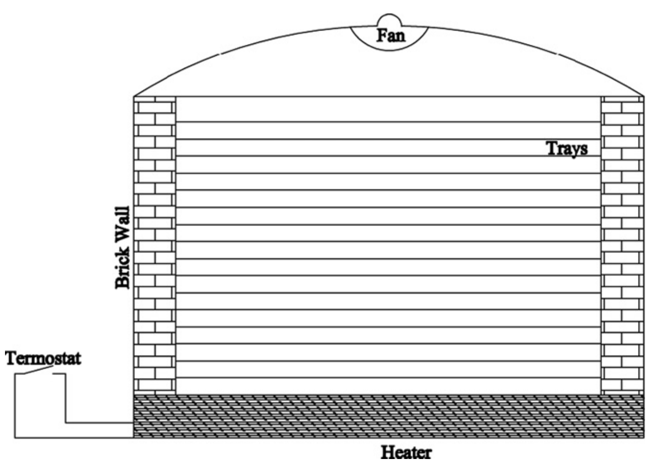


**Fig. 7.** Schematic diagram of dryer chamber.

In the cooling process, hot air fluid near the roof is drawn at first state and forced through the pipe placed in the shallow trench at the second state while from the other side irrigation aquifer water from tube well is supplied in the canal.

### 5.1. Thermal analysis

Thermal energy analyzing is the next level of design [87–91]. After passing through the cover of greenhouse, solar radiation is getting inside the greenhouse at the plants and then floor. Plants absorb the radiation and release it as the evaporation to the air the same as the floor that convict the radiation to the room air or lose it to the ground by conduction. Consequently, the surrounded air in the room is heated and then through different pores or even the cover a range a range of thermal losses transpires. The same as any other system, some parameters such as plant mass, plant area, circulating air mass flow rate and ACCFHES area have the significant effect on the system. For the plant mass effect, during the day and by considering the other parameters constant, it shows that the temperature of plant decreases as the plant mass increases according to the capacity incensement in isothermal mass heat. While, at night, this movement overturns and the temperature of plant decrease with dropping of the mass of the plant the same as operation of the winter of that by elevating the plant mass the temperature of the plant raise for off-shine hours and drop during the sunshine. The next parameter is the plant area which in the winter time and during the day by increasing the area of the plant the temperature of the air decreases. But in off-shine hours this relation also has the opposite result due to the direct ratio with the plant mass. And for summer time as solar radiation absorbed by the plants which causes the plant evaporation increase, therefore, the temperature of the plant drops by raising the plant area while it reverse for off-shine hours.

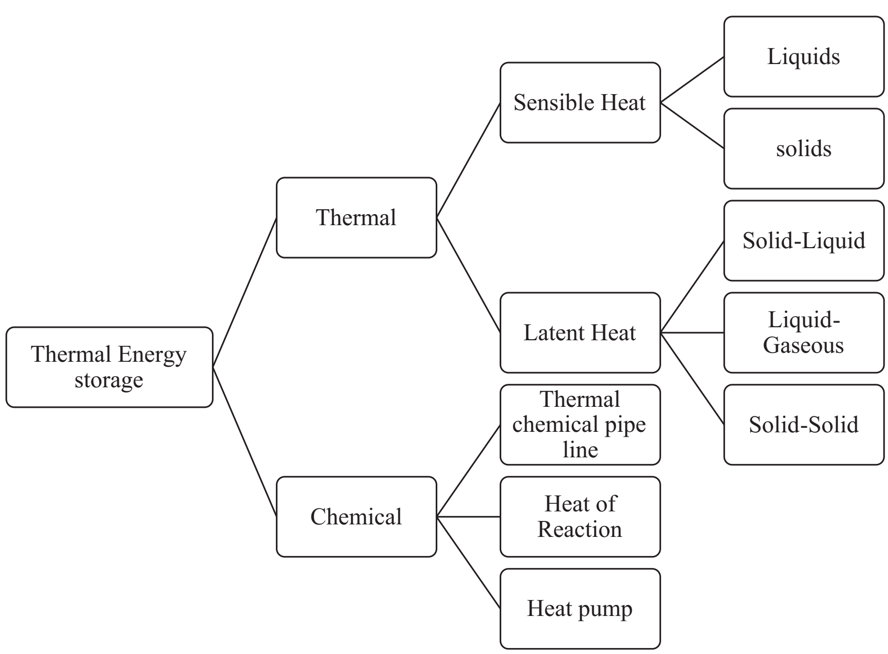


**Fig. 8.** Overview of different types of solar energy thermal storage [71].

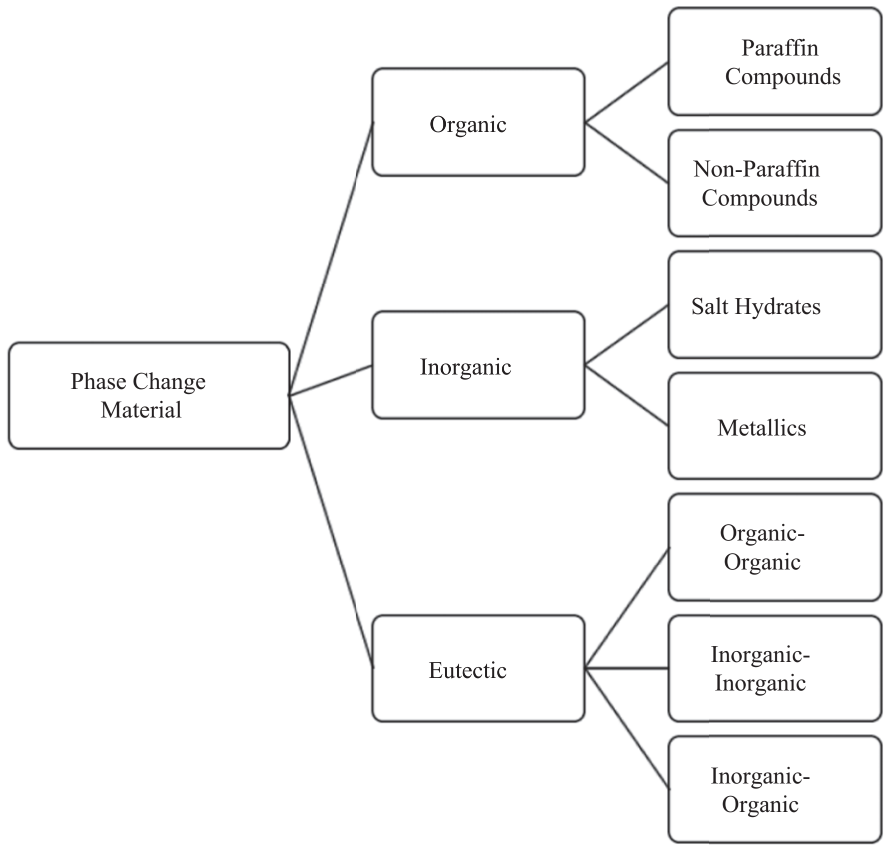


**Fig. 9.** Schematic classification of phase change material [71].

## 6. Conclusion

The application of solar energy in the agricultural sector was reviewed and presented in this paper. Different types of solar systems in each part were discussed, and it has been proven that photovoltaic systems and/or solar thermal system would be the suitable options in agricultural application and especially for the distant rural area since the solar system in different parts of agriculture makes the systems maintenance free while has no impact on the environment. However, the cost of the system is a major factor to choose the source of energy while the initial cost of the solar system needs more studies, and it makes the system more sensitive to the proper design. Moreover, the efficiency of the solar systems specially photovoltaic systems need to be considered and improved to enthusiasm governments to invest and rely more on the alternative energies rather than fossil fuels while in the past few decades by permanent increasing in the cost of conventional energy, the majority of governments become more interested to associate with renewable energy sources to support their industries and society's requirements, which cause a considerable improvement in the solar sector.

Therefore, by permanent increasing in the cost of conventional energy, majority of governments become more interested to associate with renewable energy sources to support their industries and society requirements, which causes a considerable improvement in the solar sector.

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